OPTION 2K
HEAVY-DUTY HYBRID ELECTRIC VEHICLES

Summary

Heavy-duty hybrid electric vehicles (HHEVs) combine internal combustion engines running on gasoline, diesel, natural gas, or hydrogen with an electric motor to improve vehicle fuel economy by 50 to 100 percent[1] or more. A computer determines the most efficient combination based on operating conditions and driver demand. The standard engine size is reduced, for example, from a six cylinder version to a four cylinder version, because of the added power provided by the electric motor. Energy storage devices such as batteries or ultra-capacitors capture and store energy during regenerative braking operations. The best opportunities for hybrid electric powertrains exist with heavy vehicles in Classes 3-7 or vehicles with a gross vehicle weight rating (GVWR) of 14,000 lbs to 33,000 lbs.[2] However, there are opportunities in selected Class 8 applications.

Suitable for a number of niche applications such as transit buses, garbage trucks, and package/beverage delivery vehicles, HHEVs are likely to impact petroleum demand in California in varying degrees. In the near-term (one to five years), the impact will be negligible. In the mid-term (5 to 12 years) or by 2010, HHEVs may represent less than one-tenth of one percent of the on-road heavy vehicles and reduce diesel consumption by 3.5 million gallons representing a reduction of 0.15 percent in on-road diesel demand. The impact is minor. In the long-term (12 or more years) the impact is likely to be modest. By 2025 HHEVs are projected to make up less than 1 percent of California's heavy-duty vehicle population and reduce 12.4 million gallons of diesel fuel representing a 0.54 percent reduction of the state's on-road diesel demand.

Hydraulic hybrid technology was also reviewed for this analysis. Although hydraulic hybrids appear to offer efficiency improvement benefits, minimal research and development work for this technology makes it less likely to have any impact on petroleum displacement, compared to HHEVs, over the analysis horizon.

The impact of the HHEV option compared to the petroleum option is summarized in Tables 1-4. Tables 1-4 show results for the Business-As-Usual (BAU) and Aggressive scenarios used to characterize the possible futures this option provides under three fuel price levels. A low fuel price of $1.85[3] and a high fuel price of $2.18[4] are used. The midrange price of $1.99, the average of the low and the high is also used. The BAU and Aggressive scenarios are discussed later.

Table 1: Petroleum Reduction and Benefits for Heavy-Duty Hybrid Electric Vehicle for Low Fuel Price and 5% Discount Rate

Alternative Fuel Option	Displacement in 2025, billion gallon gasoline equivalent	Reduction from Base Case Demand , percent (net gasoline and diesel)	Cumulative Benefit, Present Value 2005-2025, 5% discount rate, Billion $2005				
			A	B	C	D	A+B+C+D
			Direct Non-Environmental Benefit	Change in Government Revenue	Direct Environmental Net Benefit	External Cost of Petroleum Dependency	Direct Net Benefit
Business As Usual	0.02	0.09	(0.32)	(0.02)	0.02	0.009	(0.03)
Aggressive	0.05	0.22	(0.45)	(0.03)	0.03	0.01	(0.04)

Table 2: Petroleum Reduction and Benefits for Heavy-Duty Hybrid Electric Vehicle for Low Fuel Price and 12% Discount Rate

Alternative Fuel Option	Displacement in 2025, billion gallon gasoline equivalent	Reduction from Base Case Demand , percent (net gasoline and diesel)	Cumulative Benefit, Present Value 2005-2025, 12% discount rate, Billion $2005				
			A	B	C	D	A+B+C+D
			Direct Non-Environmental Benefit	Change in Government Revenue	Direct Environmental Net Benefit	External Cost of Petroleum Dependency	Direct Net Benefit
Business As Usual	0.02	0.09	(0.39)	(0.02)	0.02	0.009	(0.38)
Aggressive	0.05	0.22	(0.57)	(0.01)	0.03	0.01	(0.54)

Table 3: Petroleum Reduction and Benefits for Heavy-Duty Hybrid Electric Vehicles for High Fuel Price and 5% Discount Rate

Alternative Fuel Option	Displacement in 2025, billion gallon gasoline equivalent	Reduction from Base Case Demand , percent (net gasoline and diesel)	Cumulative Benefit, Present Value 2005-2025, 5% discount rate, Billion $2005				
			A	B	C	D	A+B+C+D
			Direct Non-Environmental Benefit	Change in Government Revenue	Direct Environmental Net Benefit	External Cost of Petroleum Dependency	Direct Net Benefit
Business As Usual	0.02	0.09	(0.07)	(0.02)	0.02	0.009	(0.06)
Aggressive	0.05	0.22	(0.06)	(0.03)	0.03	0.01	(0.05)

Table 4: Petroleum Reduction and Benefits for Heavy-Duty Hybrid Electric Vehicles for High Fuel Price and 12% Discount Rate

Alternative Fuel Option	Displacement in 2025, billion gallon gasoline equivalent	Reduction from Base Case Demand , percent (net gasoline and diesel)	Cumulative Benefit, Present Value 2005-2025, 12% discount rate, Billion $2005				
			A	B	C	D	A+B+C+D
			Direct Non-Environmental Benefit	Change in Government Revenue	Direct Environmental Net Benefit	External Cost of Petroleum Dependency	Direct Net Benefit
Business As Usual	0.02	0.09	(0.15)	(0.02)	0.02	0.009	(0.14)
Aggressive	0.05	0.22	(0.20)	(0.01)	0.03	0.01	(0.17)

Scenarios Description

HHEVs operate with different fuel and powertrain configurations at different levels of hybridization. HHEVs may operate on gasoline, diesel, natural gas, or hydrogen in parallel or series configuration. HHEVs may be mild or full hybrids. While still an emerging technology, HHEVs are historically deployed in transit bus and trash truck applications. Federal Express has teamed with Eaton Corporation to deploy a diesel hybrid electric package delivery vehicle.[5] Future applications are not likely to expand to applications such as long-haul vehicles.

Two scenarios are considered for this analysis. The BAU scenario assumes modest penetration of no more than 1 percent per year[6] of the combined population of transit buses. This scenario also assumes negligible penetration of the refuse and package delivery segments. The aggressive scenario case assumes a moderate penetration of 2 percent[7] of the combined population of transit buses, refuse trucks, and package delivery vehicles.[8]

Business-As-Usual Scenario

This scenario assumes that no significant hybrid vehicle technology integration on heavy vehicle platforms occur in the immediate future (1 to 5 years from now). Today's high incremental cost ($15,000 to $100,000)[9] of HHEVs compared to conventional types is a barrier to adoption of the technology in significant numbers in the market place. Few customers are aware of the option. Other potential end users may hesitate to acquire a new transportation technology. These two factors keep HHEVs small in numbers and demonstration applications.

Aggressive Scenario

This scenario assumes that 10 percent[10] of the vehicle classes and platforms with driving cycles that make sense for HHEVs adopt the technology. The scenario assumes that the combination of fuel savings, volume production, and incentives that eliminate or reduce the incremental cost to end users spur the adaptation of the technology in suitable applications. Research indicates that the incremental cost of the HHEV is likely to drop by 60 to 80 percent by the 2017 to 2025 timeframe when a mature market for this product is expected to develop. These factors combine to produce an increase in HHEVs from around 100 today to nearly 1,000 in the state's vehicle population by 2017.

Key Input Parameters and Values

The key inputs for this option are the incremental cost of the technology compared to conventional diesel engine platform. Argonne National Laboratory estimates that the incremental cost for Class 3-5 HHEV will approximate $3,00 by 2020; and the estimated incremental cost for Class 6-7 HHEV is projected to approximate $3,300 by 2020.[11] Another key input in the analysis is the 50 percent to 100 percent increase in the fuel economy of the base vehicle.[12,13] These factors affect a third crucial input, the HHEV market penetration rate and population in this analysis. This analysis amortizes the incremental cost, where applicable, over the fuel consumed during the useful life of the vehicle and application. This treatment reduces the cost savings to the consumer or end user of the technology. Similarly, maintenance cost items are applied on a per gallon basis. We assume that the maintenance cost for the HHEV is the same as the standard diesel vehicle because there is negligible data documenting the maintenance cost of HHEVs. For this analysis, the benefit to the consumer is adjusted by subtracting this cost from the annual cost savings to the consumer arising from the more efficient vehicle technology.

Key of Assumptions

- Series hybrid configurations dominate the population of HHEVs because most hybrid electric propulsion systems being developed in the U.S. feature a series arrangement.[14]
- Based on historical product development, prototyping, and commercialization trends, we also assume that the likely application for HHEVs is transit and trash truck applications with moderate penetration into the package delivery vehicle segment. Other opportunities for HHEV technology are the airport Ground Service Equipment, Utility/Specialty equipment, airport parking lot, and car rental shuttles.

Results

<u>Business as Usual Scenario</u>

For the Business as Usual Scenario, heavy-duty hybrid electric vehicles reduce California's on-road diesel demand by 18.2 million gallons or about 0.09% of combined diesel-gasoline demand in 2025.

Net-Direct benefits to the state under this scenario and a 5 percent discount rate and low fuel price of $1.82 per gallon are estimated to be a loss of $0.03 billion through 2025. Net-Direct benefits to the state under this scenario and a 12 percent discount rate and low fuel price of $1.82 per gallon are estimated to be a loss of $0.38 billion through 2025.

Net-Direct benefits to the state under this scenario, a 5 percent discount rate and high fuel price of $2.18 per gallon are estimated to be a loss of $0.06 billion through 2025. Net-Direct benefits to the state under this scenario, a 12 percent discount rate and high fuel price of $2.18 per gallon are estimated to be a loss of $0.14 billion through 2025.

<u>Aggressive Scenario</u>

For the Aggressive Scenario, heavy-duty hybrid electric vehicles reduce California's on-road diesel demand by 49.5 million gallons or about 0.22 percent of combined on-road diesel-gasoline demand in 2025.

Net-Direct benefits to the state under this scenario and a 5 percent discount rate and low fuel price of $1.82 per gallon are estimated to be a loss of $0.04 billion through 2025. Net-Direct benefits to the state under this scenario, a 12 percent discount rate and low fuel price of $1.82 per gallon are estimated to be a loss of $0.54 billion through 2025.

Net-Direct benefits to the state under this scenario, a 5 percent discount rate and high fuel price of $2.18 per gallon are estimated to be a loss $0.05 billion in 2025. Net-Direct benefits to the state under this scenario, a 12 percent discount rate and high fuel price of $2.18 per gallon are estimated to be a loss of $0.17 billion through 2025.

KEY DRIVERS AND UNCERTAINTIES

The following key drivers and uncertainties are identified and known to affect this option.

- Potential cost savings from hybridization.
- Higher fuel economy of 50 percent to 100 percent more than the standard diesel engine platform[15].
- Cost to replace new battery or other energy storage device maintenance.
- Market acceptance.
- Durability and reliability.
- Manufacturer field support and warranty.

End Notes

[1] "New Fedex Express Hybrid Electric Trucks Begin Service," Press Release, March 30, 2004.

[2] An, Feng et al. "Scenario Analysis of Hybrid Class 3-7 Heavy Vehicles," Argonne National Laboratory, SAE Paper 2000-01-0989.

[3] "Summary of Retail Price Scenarios for 2025," California Energy Commission Staff, February 24, 2005.

[4] Ibid.

[5] "New Fedex Express Hybrid Electric Trucks Begin Service," Press Release, March 30, 2004.

[6] Beverage Delivery and Regional Heavy Distribution Working Group, Hybrid Truck Users Forum, http://www.calstart.org/programs/htuf/Parcel_&_Delivery_Working_Group_Pop_Up.html

[7] Calculated historical penetration rate of selected technologies onto vehicle platforms. Ward's Automotive.

[8] Ibid.

[9] Ibid.

[10] Personal Communication with Mike Simon of ISE Corporation on January 27, 2005.

[11] An, Feng et al. "Scenario Analysis of Hybrid Class 3-7 Heavy Vehicles," Argonne National Laboratory, SAE Paper 2000-01-0989.

[12] http://www.auto-careers.org/diesel_hybrid_info.htm.

[13] 21st Century Truck Program, U.S. Department of Energy, October 2001.

[14] An, Feng et al. "Scenario Analysis of Hybrid Class 3-7 Heavy Vehicles," Argonne National Laboratory, SAE Paper 2000-01-0989.

[15] Parcel and Delivery Working Group, Hybrid Truck Users Forum presentations http://www.calstart.org/programs/htuf/Parcel_&_Delivery_Working_Group_Pop_Up.html.